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Web-SCADA for Monitoring and Controlling Hybrid Wind-PV Power System

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Abstract

This paper presents the implementation of Web-SCADA on the hybrid wind-PV power system. Both the electrical paramaters such as current, voltage, power and the environment parameters such as wind speed, solar irradiation, and PV temperature are monitored remotely via Internet using a web browser. The SCADA system allows the user to control the hybrid power system remotely. The low cost sensor systems, RTUs and PLC are developed for implementing the SCADA system. The IntegraXor SCADA is employed as the Web-SCADA software. It provides the easy way for developing the Web-based SCADA application. The experimental results show that the Web-SCADA works properly in the monitoring and controlling the hybrid power system. The developed sensor systems provides the average error of 2.87%. The developed RTUs are able to acquire the sensor data and communicate with the SCADA server in real-time.

Keywords: *Web-SCADA, hybrid power system, RTU, PLC, IntegraXor, sensor*

1. Introduction

Recent developments in renewable energy resources increase significantly. A hybrid technology that combines several renewable resources becomes a common trend, such as the hybrid wind-solar power systems [1]-[5]. Due to its nature, the hybrid power systems are usually located separately in rural area. To control and monitor them remotely, the SCADA (Supervisory Control and Data Acquisition) systems were employed in [6]-[9]. The SCADA system could monitor the real-time electrical data measurement of the hybrid power system consists of wind turbine, solar modules, and battery [6]. The measurement data was transferred to the web-based remote monitoring center. In [7], the SCADA system was employed for energy flow management. They showed that the SCADA system provides an effective decision-making to manage the energy availabily of renewable energy resources (wind, solar, and hydro power) to the consumers.

The other approaches to use SCADA systems in the renewable energy resources are for monitoring the wind turbine [8] and the sun tracker system [9]. In [8], the SCADA system was used to gather the information of wind turbine such as the condition of gearbox, blades, electric system, etc. Then the collected SCADA data was analyzed for early warning of the wind turbine's failure. In [9], an intelligent sun tracker was proposed to optimize the solar power energy. In the system, actual power and position of sun tracked were monitored by the SCADA system.

In this paper, the SCADA is implemented for monitoring and controlling the hybrid power system. Compared to the existing systems [6]-[9], our system monitors both electrical and environment parameters. Further, a web-based SCADA is employed to allow users to monitor and control the system via Internet. This work extends our previous work [10], where the hybrid power plant is simulated using software.
The rest of paper is organized as follows. Section 2 describes the architecture of proposed Web-SCADA system. Section 3 describes the design of Web-SCADA system. The experimental results are discussed in section 4. Conclusion is covered in section 5.

2. System Architecture

Figure 1 illustrates the architecture of proposed SCADA system. A Web-based SCADA software (IntegraXor [10]) is employed as the SCADA web server. The server is connected to

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the RTU (Remote Terminal Unit) and PLC (Programmable Logic controller) for exhanging the information on the hybrid wind-PV power system. The server is connected to Internet, so users could access them via Internet using the standard web browsers.

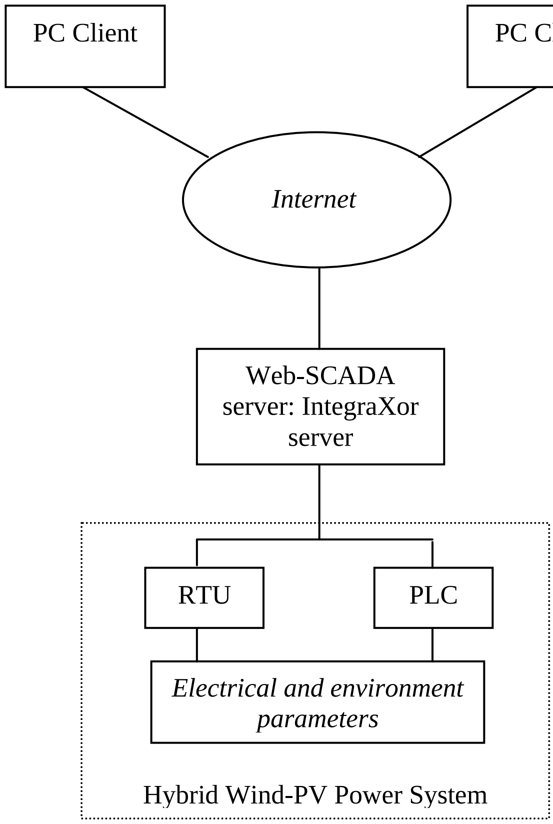


Figure 1. SCADA architecture.

The server is also connected to the RTU and PLC on the hybrid power system using serial communication and local area network respectively. RTU and PLC are the field devices to read data from the sensors and send command to the actuators.The RTU and PLC are chosen by considering the costs and the practical implementation of sensor systems as described in the next section.

The hardware configuration of proposed SCADA is shown in Figure 2. As shown in the figure, the hybrid power system consists of wind power, solar panel and battery storage. In the system, the DC-bus method is adopted to link all energy resources and the load. The control scheme of hybrid power system is to connect/disconnect the power resources, battery and load from the DC-bus in order to optimize the energy supply. A PLC provides the signal controls for connecting/disconnecting them. The PLC is connected to SCADA server using LAN (Local Area Network).

There are two RTUs connected to SCADA server for reading the data from sensors. Both RTUs are communicated with the server using RS-485 serial communication. Two kinds of sensors are employed, i.e.: a) sensors for collecting the environmental parameters; and b) sensors for collecting the electrical parameters. The environmental parameters to be monitored are: solar irradiation, temperature of PV module, wind speed, and wind direction. While the electrical parameters to be monitored are: voltage and current of the wind power system, voltage and current of the solar power system, voltage and current of the DC-bus, voltage and current of the battery, and voltage and current of the load.

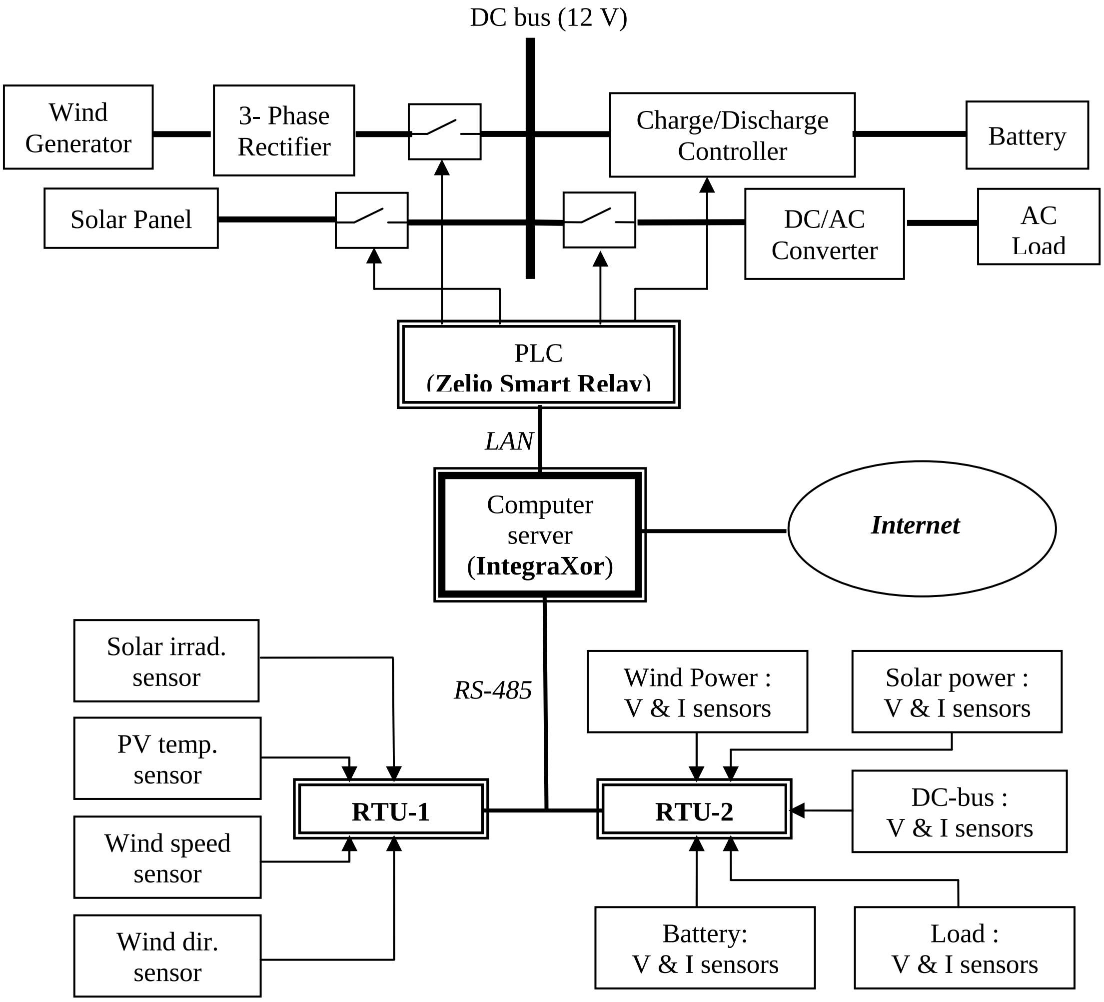


Figure 2. Hardware configuration of SCADA system

3. SCADA Design
3.1. Hardware Design

The proposed Web-SCADA is designed to control and monitor a small scale hybrid power system developed on Department of Electrical Engineering, National Institute of Technology Malang, Indonesia. The hybrid power system consists of 200 Watt wind power system, 6 x 50 Watt solar power system, and 100Ah lead crystal battery. Figure 3 shows the wind-PV system which was installed on the third floor of laboratory building.

As shown in Figure 2, a PLC is employed to control the hybrid power system and two RTUs are employed to collect the data from sensors. The Zelio Smart Relay, a small and cheap PLC from Schneider Electric, is chosen in the implementation. Due the limitation of the number of analog inputs and the capability to read the sensors, the Zelio Smart Relay is only used to control the hybrid system. While the sensors are handled by two RTUs. The RTUs are developed based on the low cost AVR ATmega8535 microcontroller system. By developing such microcontroller system, various sensor modules could be acquired easily.

Figure 4 illustrates the block diagram of developed RTUs and sensor modules. Microcontroller#1 is used to acquire the environment data from solar irradiation sensor, wind speed sensor, wind direction sensor, and PV-temperature sensor. These sensors, except the wind speed sensor, are connected to the microcontroller via the analog input (PA0,PA1,PA2). While the wind speed sensor is connected via the digital input (PD2). The configurations of the sensors are described in the following.

Figure 3. Wind-PV power system.

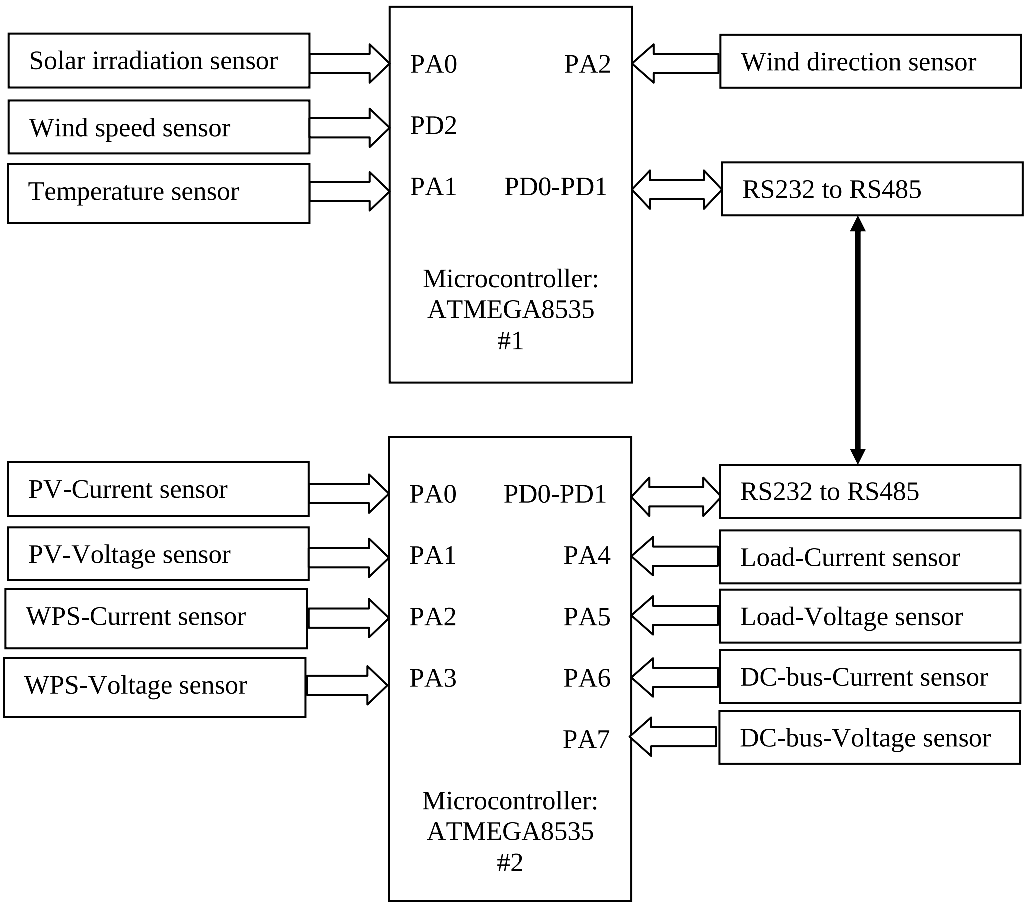


Figure 4. Block diagram of RTUs and sensor modules.

Figure 5. Weather station module (Argent Data System).

A common method for measuring solar irradiation is using a pyranometer. Unfortunately the price of such sensor is expensive. In this work, a low cost PV module is employed to measure the solar irradiation. Since the voltage of PV module depends on the solar irradiation that falls into the module, the PV module could be used to measure the solar irradiation based on its output voltage. A small size PV module (7cm x 5.5cm) is employed. It has a nominal output voltage of 10 V and output current of 30 mA. Since the maximum voltage of analog input of the microcontroller is 5 V, a simple voltage divider is added.

To measure the temperature of PV module, an integrated circuit temperature sensor LM35 is employed. The sensor chip produces a voltage which is proportional to the temperature, where increasing the temperature of 1 ^{0}C causes increasing voltage of 10 mV. A multiplier circuit is added to the output of sensor, thus the output voltage is 5 V when the temperature is 100 ^{0}C.

A weather station module from Argent Data System as shown in Figure 5 is employed to measure the wind direction and speed. The wind direction sensor has eight switches which are connected to eight different resistors. The module is arranged so 16 different positions could be determined by closing two switches at once. Then a voltage divider circuit is added to interface the module with the analog input of microcontroller.

The wind speed sensor is a cup-type anemometer with a switch which is closed when the cup rotates. The wind speed of 2.4 km/h causes the switch closes once per second. To measure the wind speed, the number of pulses generated by the sensor should be counted. Thus the sensor is connected to the digital input of microcontroller. In this case, the external interrupt port (PD2) is employed.

The voltage and current sensors are employed to measure the electrical data of hybrid power system. Once the voltage and current are measured, then the electrical power is calculated by the microcontroller. Since the voltage of DC bus is 12 V, a simple voltage divider is employed to step down the voltage to the range of 0 – 5 V before connected to the analog input of the microcontroller.

To measure the current, the integrated current sensor ACS712 is employed. The sensor is a hall-effect type current sensor which produces the output voltage proportional to the current flows on it. The output voltage changes by 100 mV when the current changes by 1 A. When there is no current, the output voltage is 2.5 V. A voltage divider is added to interface the sensor with the microcontroller.

3.2. Communication System

An ethernet extension modue is added to PLC Zelio Smart Relay to allow the PLC communicates with the Web-SCADA server via LAN using MODBUS TCP protocol [11]. While both RTUs are connected to the Web-SCADA server using RS485 serial communication. To communicate with the server, the MODBUS RTU should be developed on the RTU [11]. Fortunately, the MODBUS RTU protocol could be implemented on ATMega8535 microcontroller easily. Table 1 and 2 show the allocation of MODBUS addresses for PLC (MODBUS TCP) and RTUs (MODBUS RTU) respectively.

Table 1. The allocation of MODBUS TCP addresses.

No.	Variable Name	MODBUS TCP Address
1.	Wind power disconnecting relay	16
2.	PV disconnecting relay	17
3.	Battery charge controller	18
4.	Load disconnecting relay	19

Table 2. The allocation of MODBUS RTU addresses.

No.	Variable Name	MODBUS RTU Address
1.	Solar irradiation sensor	16
2.	PV temperature sensor	17
3.	Wind direction sensor	18
4.	Wind speed sensor	19
5.	PV-Current sensor	20
6.	PV-Voltage sensor	21
7.	Wind power-Current sensor	22
8.	Wind power-Voltage sensor	23
9.	Load-Current sensor	24
10.	Load-Voltage sensor	25
11.	DC-bus-Current sensor	26
12.	DC-bus-Voltage sensor	27

3.3. Software Design

In this work, IntegraXor software [12] is used for implementing the Web-SCADA. To run the Web-SCADA application, the IntegraXor server should be installed on the computer server and users could view the graphical interface using the web browser which is equipped with Adobe SVG viewer. The IntegraXor provides the graphical tools (Inkscape SAGE) for developing the graphical interface.

The main display of Web-SCADA contains the graphical animation of the controlled hybrid power system and the monitored environmental and electrical parameters. Thanks to IntegraXor and Inkscape SAGE which provide the easy way for developing the web-based graphical animation. The front-end display consists of five sub-systems, i.e. wind power, solar power, battery, DC-bus, and load sub-systems as shown in Figure 6.

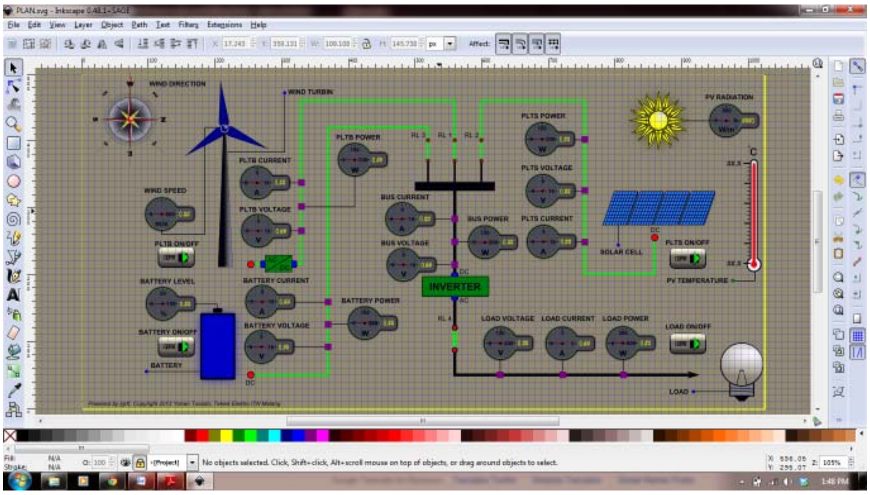


Figure 6. Web-SCADA front-end display

The meter animation displays are used to visualize the current, voltage, and power in the hybrid power system. The ON/OFF buttons are used to visualize the power switches for connecting/disconnecting the hybrid power sub-systems from the DC-bus. The colored lines are used to visualized the current flow, where the color will change when the current flows.

In the wind power sub-system, the meter animation display is used to visualize the wind speed. The wind direction is visualized by the compass animation display. In addition, a wind turbine animation will rotate according to the wind speed. In the solar power sub-system, the solar irradiation is visualized by a meter animation display. The thermometer animation display is used to visualize the PV temperature. In the battery sub-system, the state of charge (SOC) of the battery is visualized by a gauge animation display.

4. Experimental Results

The proposed Web-SCADA is implemented in real hybrid power system and several experiments are conducted. The experiments cover the developed sensor systems, the functionality of Web-SCADA system, and the Web-SCADA features.

Since the low cost sensor systems are developed, the measurement errors are calculated with respect to the calibrated instruments as listed in Table 3. As shown in the table, the measurement error of current sensor is the highest among the others. From the observation it is obtained that the high error is caused by the fact that the ACS712 current sensor is suitable for sensing the high current, while the current in the hybrid system is relative low. It is worthy to note that the measurement error of low cost solar irradiation sensor is low.

Table 3. The measurement errors of developed sensor systems.

No.	Sensor module	Measurement error	Calibrated instrument
1.	PV-Current sensor	7.62 %	Standard
2.	Wind power-Current sensor	4.99 %	Amperemeter
3.	PV-Voltage sensor	0.27%	Standard Voltmeter
4.	Wind power-Voltage sensor	1.18%	
5.	Solar irradiation sensor	0.38%	Solar Power Meter TM-750
6.	PV-temperature sensor	1.80%	Standard thermometer
7.	Wind speed sensor	3.85%	Anemometer Luxtron AM-420
	Average	2.87%	

To verify the monitoring and control functions of the Web-SCADA, the monitoring and control tasks displayed on the web browser are observed and compared with the manual inspection. The experimental results show that all control and monitor tasks work properly. Figure 7 shows the wind power sub-system animation display. In the figure, the wind speed is 23 m/s, the generated current, voltage, and power are 12 A, 13 V, and 156 W respectively. The power switch is ON as indicated by the ON/OFF button in ON position and the power relay (RL1) is closed.

Besides the monitoring and controlling functions, the common SCADA features such as trending, alarm and report are also tested. Figure 8 shows the trending display of solar power system. In the figure, PV temperature, solar irradiation, the current, voltage, and power of solar power system are plotted against the time in real time. When the alarms are occured, they are displayed on the alarm display as shown in Fig. 9. In the figure, the alarms are occured when the voltage of DC-bus are lower than 10.5 V. The SCADA report of DC-bus (Figure 10) summaries the values of DC-bus current, voltage, and power. The timestamp data, average, minimum and maximum values are reported.

The results show that the proposed system is superior to the previous systems [6]-[7], in the sense that both electrical and environment data are monitored via the Web-SCADA.

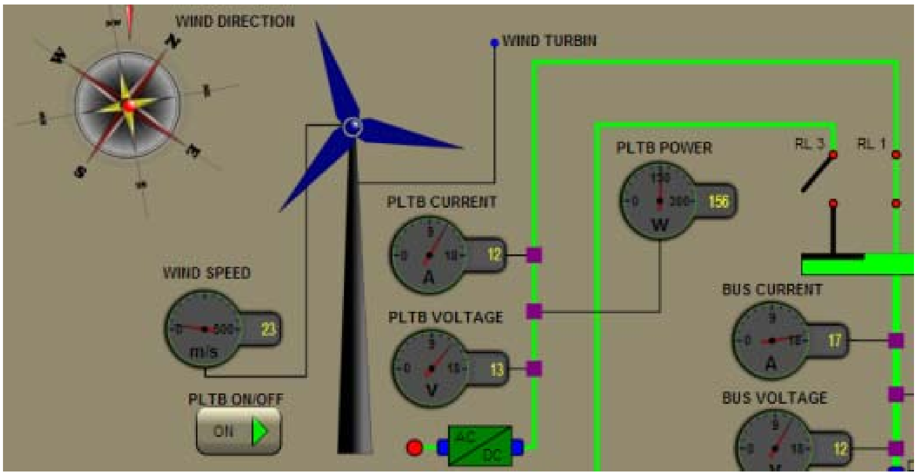
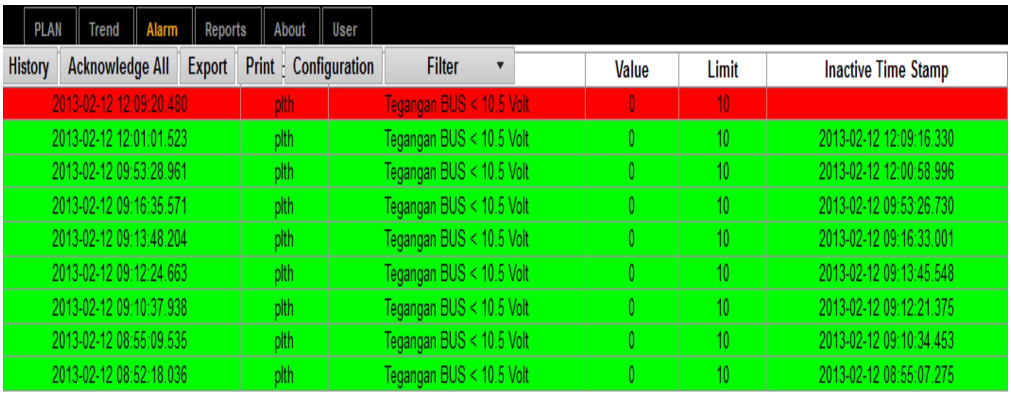


Figure 7. Wind power sub-system animation display.

Figure 8. Trending display of solar power system



		Filter	Value	Limit	Inactive Time Stamp
2013-02-12 12:09:20.480	plth	Tegangan BUS < 10.5 Volt	0	10	
2013-02-12 12:01:01.523	plth	Tegangan BUS < 10.5 Volt	0	10	2013-02-12 12:09:16.330
2013-02-12 09:53:28.961	plth	Tegangan BUS < 10.5 Volt	0	10	2013-02-12 12:00:58.996
2013-02-12 09:16:35.571	plth	Tegangan BUS < 10.5 Volt	0	10	2013-02-12 09:53:26.730
2013-02-12 09:13:48.204	plth	Tegangan BUS < 10.5 Volt	0	10	2013-02-12 09:16:33.001
2013-02-12 09:12:24.663	plth	Tegangan BUS < 10.5 Volt	0	10	2013-02-12 09:13:45.548
2013-02-12 09:10:37.938	plth	Tegangan BUS < 10.5 Volt	0	10	2013-02-12 09:12:21.375
2013-02-12 08:55:09.535	plth	Tegangan BUS < 10.5 Volt	0	10	2013-02-12 09:10:34.453
2013-02-12 08:52:18.036	plth	Tegangan BUS < 10.5 Volt	0	10	2013-02-12 08:55:07.275

Figure 9. SCADA alarm display

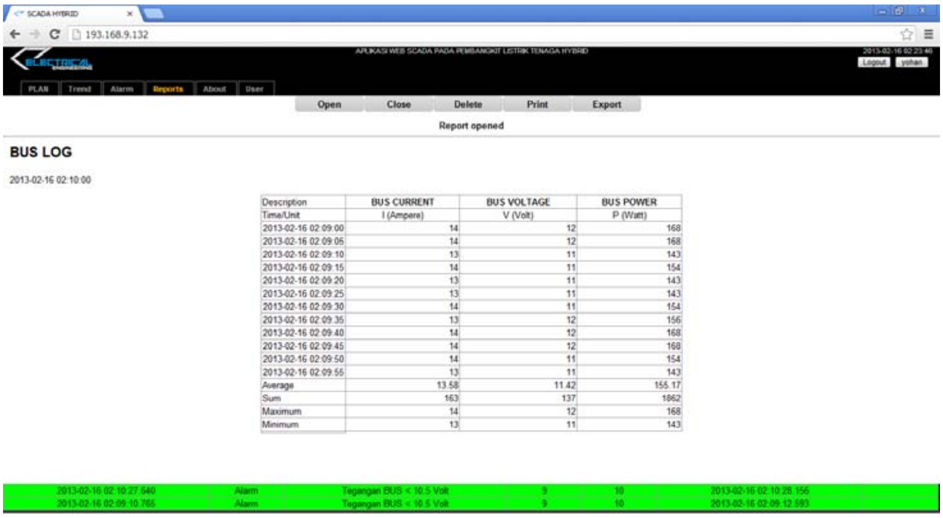


Figure 10. SCADA report display of the DC-bus

5. Conclusion

The Web-SCADA is implemented for monitoring and control the hybrid power system. The sensor systems and RTUs are developed to collect data of the electrical and environment parameters which are sent to the Web-SCADA server. While the control command is sent by the Web-SCADA server to PLC for controlling the hybrid power system. The developed Web-SCADA system is tested on the 500 W hybrid wind-power system and shows a good result, in the sense that the Web-SCADA is able to monitor and control the hybrid power system remotely via the web browsers.

In future, the SCADA system will be extended to monitor and control the more complex hybrid power systems. Further, the communication networks and the security issues will be addressed.

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